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(54) **Three-dimensional printing techniques**

Dreidimensionale Drucktechniken

Techniques d'impression tri-dimensionnelle

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(56) References cited:
WO-A-90/03893
DE-A- 2 263 777
US-A- 4 247 508
US-A- 4 863 538

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Description

Introduction

This invention relates generally to the manufacture of tooling and prototype parts and, more particularly, to the use of three-dimensional printing techniques using computer models therefor.

Background of the Invention

Two needs in providing effective industrial productivity and competitiveness lie in the reduction in time required to bring new products to the marketplace and the need for providing for flexible manufacture of products in small quantities. Thus, it is desirable to provide rapid part turnaround with a minimal investment in tooling. Techniques for doing so should have the ability to tailor designs to specfic tasks, to shorten the cycle time from design to manufacturing, and/or to manufacture in very small lot sizes, as low as a single component, all at reasonable cost. A major contributor to the time required to bring new products to market is the time required to fabricate functioning prototypes. Rapid prototyping can shorten the product development cycle and improve the design process by providing rapid and effective feedback to the designer. Moreover, some applications require rapid prototyping of non-functional parts for use in assessing the aesthetic aspects of a design or the fit and assembly thereof.

Another major contributor to the time to bring a product to market is the time required to develop tooling, such as molds and dies. For some types of tooling, such as injection molding dies, the turnaround time for the design and fabrication of a tool routinely extends to several months. The long lead times are due to the fact that tooling is often one of a kind and can be extremely complex, requiring a great deal of human attention to detail. Thus, tooling not only affects lead time, but also manufacturing costs as well. In fact, tooling costs often determine the minimum economic batch size for a given process. Prototyping requirements, tooling lead time, and tooling cost are related in that it is the combination of long lead times and high cost which make it impractical to fabricate preproduction prototypes by the same process that will be used in production.

In the past several years, there has been considerable interest in developing computerized, three-dimensional printing techniques, sometimes referred to as "desktop manufacturing" techniques where no tooling is required. One such system is known, the SLA 1 System, made and sold by 3D Systems, Inc. of Valencia, California. This system operates on a principle called stereolithography wherein a focused ultra-violet (UV) laser is vector scanned over the top of a bath of a photopolymerizable liquid polymer plastic material. The UV laser causes the bath to polymerize where the laser beam strikes the surface of the bath, resulting in the creation of a first solid plastic layer at and just below the surface. The solid layer is then lowered into the bath and the laser generated polymerization process is repeated for the generation of the next layer, and so on, until a plurality of superimposed layers forming the desired part is obtained. The most recently created layer in each case is always lowered to a position for the creation of the next layer slightly below the surface of the liquid bath.

An alternative approach, sometimes called Selective Laser Sintering (SLS) has also been proposed by DTM Corporation of Austin, Texas. In such system, and also disclosed in United States Patent US-A-4 863 538, a laser beam is used to sinter areas of a layer of loosely compacted plastic powder, the powder being applied layer by layer. The term "sintering" refers to the process by which particulates, such as powdered plastics, are caused to adhere into a solid mass by means of externally applied energy. A SLS system uses the optical energy supplied by a laser for such purpose.

Thus, a thin layer of powder is spread evenly onto a flat surface with a roller mechanism. The thin powder surface is then raster-scanned with a high-power laser beam from above. The powder material that is struck by the laser beam is fused together. The areas not hit by the laser beam remain loose and fall from the part when it is removed from the system. Successive layers of powder are deposited and raster-scanned, one on top of another, until an entire part is complete. Each layer is sintered deeply enough to bond it to the preceding layer. A similar laser sintering approach has been proposed by Hydronetics, Inc. of Chicago, Illinois. Another process suggested by the same company is designated as a Laminated Object Manufacturing (LOM) technique wherein thin metallic foil layers are cut out to appropriate shapes to form a part and the shaped layered pieces are laid one on top of the other and suitably bonded to form the part involved.

Another process suggested for creating 3D models and prototypes, sometimes called Ballistic Particle Manufacturing (BPM), has been proposed by Automated Dynamic Corporation of Troy, NY. This process uses an ink-jet printing technique wherein an ink-jet stream of liquid molten metal or a metal composite material is used to create three-dimensional objects under computer control, similar to the way an ink-jet printer produces two-dimensional graphic printing. A metal or metal composite part is produced by ink-jet printing of successive cross sections, one layer after another, to a target using a cold welding (i.e., rapid solidification) technique, which causes bonding between the particles and the successive layers.

Still another technique, sometimes called Photochemical Machining, proposed by Formigraphic Engine Co. of Berkeley, California, uses intersecting laser beams to selectively harden or soften a polymer plastic block. The underlying mechanism used is the photochemical cross-linking or degradation of the material.

It is further known in the prior art to make a component by a process comprising the steps of:

a) depositing a layer of particulate material in a confined region;

b) causing said layer of particulate material to become bonded at one or more selected regions;

c) repeating steps (1) and (2) a selected number of times to produce a selected number of successive layers; and

d) removing particulate material which is not at said one or more selected regions to provide the component.

Such a process and corresponding apparatus are disclosed in Feygin's International Application published as WO-A-90/03893, in which a computer directed beam of concentrated energy or matter is used to cut, fuse or change the physiochemical properties of successive thin sheets of powder based materials to build up the desired object.

In German Patent Specification DE-A-22 63 777 a process and apparatus for producing desired objects from fusible materials is disclosed, in which the material in the form of fine particles is brought into a thermal ray or rays having a very small or point focus whereby the particles are melted to form an agglomerated homogeneous mass, the shape of which depends on movement of the focus.

It is an object of this invention to devise a technique for providing such layered parts which will work satisfactorily with ceramic or metal materials, or combinations of such materials with each other or with other materials, but which will also work satisfactorily with plastic particles or with other inorganic materials. Such a technique could be more universally employed for the manufacture of components from a larger variety of materials than the currently proposed techniques.

Brief Summary of the Invention

The present invention is characterized in that a binder material is applied to selected regions of a porous layer of particulate material, and that the binder bonds the particulate material in the said selected regions and causes successive layers to become bonded to each other.

The present invention correspondingly also provides a system for making a component, comprising means for depositing a selected number of successive porous layers of a particulate material, means for causing the particulate material to become bonded at one or more selected regions in each layer to form said component, and means for removing particulate material which is not at said one or more selected regions, characterized in that the means for causing the particulate material to become bonded comprises means for applying a binder material to said selected regions of each successive layer after each successive layer has been deposited.

In accordance with a preferred embodiment of the invention, powdered material, e.g. a powdered ceramic, a powdered metal, or a powdered plastic, is deposited in sequential layers one on top of the other. Following the deposit of each layer of powdered material, a liquid binder material is selectively supplied to the layer of powdered material using an ink-j t printing technique in accordance with a comput r model of the three-dimensional part being formed. Following the sequential application of all of the required powder layers and binder material to form the part in question, the unbound powder is appropriately removed, resulting in the formation of the desired three-dimensional part. It is found that such technique permits complex metal, ceramic, or metal-ceramic composite parts to be effectively formed with a very high degree of resolution in a reasonably short time period.

Such technique should be particularly useful, for example, in providing for the rapid production of molds for metal casting and the rapid formation of pre-forms for metal matrix composites. Such technique can also be used with plastic materials to form plastic components or parts for various purposes.

Description of the Invention

The invention can be described in more detail with the help of the accompanying drawings wherein

FIG. 1 shows an isometric view of one particular embodiment of the invention;
FIG. 2 shows diagrammatic views of different stages in forming a part in accordance with the invention;
FIG. 3, 4 and 5 show various exemplary techniques for setting the powder particles by applying mechanical vibrations and acoustic energy thereto;
FIG. 6 shows exemplary stages in the use of a drop-piston device for depositing powder particles in accordance with the invention;
FIGS. 7 and 8 show diagramatic views of the formation of a part having reentrant features;
FIG. 9 shows a block diagram of an exemplary system which can be used in practicing the invention;
FIG. 10 shows an exemplary flow chart of the steps used in the system of FIG. 8 to practice the invention.
FIGS. 11 and 12 show isometric views of an exemplary 3-D model and the 2-D slices thereof, respectively, of a part to be formed in accordance with the invention; and
FIG. 13 shows a plan view of the 1-D line segments of a 2-D slice of the model shown in FIGS. 11 and 12.

One particular embodiment of the invention is shown in FIG. 1 which depicts an apparatus 10 for forming a ceramic mold having six cavities 12A-12F which can be used for casting six substantially identical parts. A powder dispersion head 13 is driven reciprocally in a shuttle motion along the length of the mold being formed. A suitable linear stepping motor assembly 18 can be used for moving the powder distribution head 13 and the binder deposition head 15 (discussed below). The powdered material, e.g., a ceramic powder, is dispensed in a con-

fined region, e.g., defined by a form 14, the powder being dispensed in a line as the dispensing head 13 is moved in discrete steps along the mold length to form a relatively loose layer thereof having a typical thickness of about 100-200 microns, for example. While the material is described here as a powdered material, in some applications it can be distributed in the form of fibers, for example. For convenience in describing the invention, the term powder material will be construed to include fiber material. The stepping motor can be moved at such high speeds that the motion of the head 13 will effectively be continuous in nature. Alternatively, the motor may be one which inherently provides a continuous motion, such as a servo-controlled motor. An initial layer is dispersed at the bottom of the form 14 and each subsequent layer is dispersed sequentially on the preceding layer.

An ink-jet print head 15 having a plurality of ink-jet dispensers is also driven by the stepping motor assembly in the same reciprocal manner so as to follow the motion of the powder head and to selectively produce jets of a liquid binder material at selected regions 16 which represent the walls of each cavity, thereby causing the powdered material at such regions to become bonded. The binder jets are dispensed along a line of the printhead 15 which is moved in substantially the same manner as the dispensing head 13 of the powder material, i.e., by a high speed stepping operation or by a continuous servo motor operation, in each case providing effectively continuous movement of head 15 as discussed above with reference to head 13. Typical binder droplet sizes are about 15-50 microns, for example. The powder/binder layer forming process is repeated so as to build up the mold parts layer by layer.

A diagram showing a part being fabricated in accordance with the invention is depicted in FIG. 2 which diagrammatically depicts the flow thereof. For a part 40 in question a layer of powder is deposited from a powder dispensing head 41 into a form 42 over a previously formed layer which has already had binder material deposited therein (A). A layer of binder material is then printed onto the powder layer from binding jet head 43 to form the next layer 44 of bonded powder articles (B). Such operation is repeated for each subsequent layer. An exemplary intermediate stage of the formation of part 40 is shown at (C). When the final bonded layer is printed as shown at (D), excess, unbonded powder is removed, the finally formed part itself being depicted at (E).

While the layers become hardened or at least partially hardened as each of the layers is laid down, once the desired final part configuration is achieved and the layering process is completed, in some applications it may be desirable that the form and its contents be heated or cured at a suitably selected temperature to futher promote binding of the powder particles. In either case, whether a further curing is or is not required, the loose, unbonded powder particles, e.g., at regions 17 (FIG. 1), are removed using a suitable technique, such as ultrasonic cleaning, for example, so as to leave a finished part for use.

For effective use, the powder particles should be uniformly deposited at a relatively high rate, the rate being selected in accordance with the application for which the technique is used. For many useful applications the powder particles can preferably be packed at relatively high densities, while in other applications the density may be considerably lower where parts having greater porosity are desired. Known techniques used in the fields of colloidal science and powder dispersion chemistry can be used to provide the desired uniform depositions of such powders at the required rates and densities. Thus, such powders can be dispensed either as dry powders or in a liquid vehicle, such as in a colloidal dispersant or in an aqueous suspension. In the dry state, the desired compaction of particles can be achieved using mechanical vibrating compaction techniques or by applying acoustic energy, i.e., either sonic or ultrasonic vibrations, to the deposited powder or by applying a piezoelectric scraper to the deposited powder.

Such techniques are illustrated, for example, in FIGS. 3, 4 and 5, respectively. FIG. 3 shows form 14 which is mechanically vibrated as shown by arrow 60 using a vibrating transducer system 61 for settling the powder particles 62 therein. In FIG. 4 a acoustic transducer system 63 is used to supply acoustic energy 64 to the surface layer of powder 62 for such purpose. In FIG. 5 a vibrating tranducer system 65 is used to vibrate a piezoelectric scraper 66 as shown by arrow 67 as it moves in the exemplary direction of arrow 68 to settle the powder 62.

The powder may also be deposited in a dry or in a wet form using a drop piston approach wherein a dry or moist powder is deposited on the top of a vertically movable piston and the piston is moved downwardly into a chamber, excess powder being scraped off with a suitable scraper device.

As shown in FIG. 6, a piston 70 holds the part 71 shown as partially formed within a chamber 72 at diagram (A). In order to deposit a layer of powder, the piston is moved downwardly in the chamber, leaving a region in chamber 73 at the top thereof for deposition of powder particles at diagram (B). Powder particles 74 are deposited in such region and a doctor blade 75, for example, is used to scrape off excess powder at diagram (C). The part 71 having the newly deposited layer 76 of powder thereon is then ready for the application of binder material thereto at diagram (D).

In general, it is found that larger particles, for example, of about 20 microns or greater in size, are preferably deposited in a dry state, while smaller particles, for example, of about 5 microns or smaller in size, can be deposited either in a dry state or in a wet state in a liquid vehicle.

Colloidal dispersions of particles can be obtained in a liquid vehicle by the addition of chemical dispersants. The liquid used in a wet powder dispersion technique is removed, or partially removed, before the next layer is deposited. Thus, such liquid is caused to evaporate rapidly before the ink-jet binder printing occurs. Such evap-

oration can be achieved, for example, by using infra-red heating, hot air heating or microwave heating techniques.

The ink-jet printing of the binder material should utilize droplets of materials the shrink characteristics of which are selected so that the dimensional tolerances of the part being made are maintained upon hardening thereof. While the binder solution must have a relatively high binder content, the viscosity thereof should be low enough so as to be able to flow through the printing head for deposit into the powder material. The binder material should be selected to penetrate the layer and to perform its binding action relatively rapidly in each layer so that the next layer of powder particles can be subsequently applied thereto. When using certain ink-jet technology the binder material may require at least a minimum electrical conductivity, particularly when using currently available continuous jet printing heads, for example, which require enough conductivity to establish charge on the binder solution droplets as they are emitted from the head. Where conductivity cannot be established in the binder, as with certain organic solvents, for example, the binder can be applied using drop-on-demand print heads.

The binder material may be such that the bonded particles have a high binding strength as each layer is deposited so that, when all the layers have been bonded, the component formed thereby is ready for use without further processing. In other cases, it may be desirable, or necessary, to perform further processing of the part. For example, while the process may be such as to impart a reasonable strength to the component which is formed, once the part is formed it can be further heated or cured to further enhance the binding strength of the particles. The binder in some cases can be removed during such heating or firing process, while in others it can remain in the material after firing. Which operation occurs depends on the particular binder material which has been selected for use and on the conditions, e.g., temperature, under which the heating or firing process is performed. Other post-processing operations may also be performed following the part formation.

The ink-jet printing mechanisms that can be used are known to the art and normally are of two types, one being a continous jet stream print head and the other a drop-on-demand stream print head. A high speed printer of the continous type, for example, is the Dijit printer made and sold by Diconix, Inc. of Dayton, Ohio, which has a line printing bar containing approximately 1500 jets which can deliver up to 60 million droplets per second in a continous fashion and can print at speeds up to 900 feet per minute. In such a system, the liquid material emerges continuously from each jet nozzle under high pressure, the jet stream then disintegrating into a train of droplets, the direction of which is controlled by electric control signals.

Drop-on-demand systems, as now known to the art, generally use two droplet generation mechanisms. One approach uses a piezoelectric element which in one exemplary embodiment has the piezoelectric element attached to one wall of a liquid reservoir. A pulse applied to the piezoelectric element slightly changes the volume of the reservoir cavity and simultaneously induces a pressure wave in th liquid. Such operation causes a droplet of the liquid to be ejected from a nozzle attached to the cavity. The cavity refills by capillary action. Another approach uses an evaporative bubble wherein a small resistive heater when actuated causes some of the liquid to evaporate so as to form a vapor bubble which in turn causes a small droplet of liquid to be ejected from the cavity. The cavity is then refilled through capillary action. In general, continuous jet technology provides higher droplet deposit rates than drop-on-demand technology.

The continuous or drop-on-demand ink-jet heads may use, for example, a single jet, or an array of jets which are arranged to deposit the material in an effectively linear manner, or a combination of two or more relatively short, parallel arrays of jets arranged for parallel and effectively linear depositions thereof.

The rate at which a ceramic, metal, plastic, or composite component can be made depends on the rates used to deposit the powder and to supply the binder liquid, and on the rate at which each bonded layer hardens as the layers are deposited one on the other.

If a dry powder dispersion is utilized, the powder application step is less significant as a limiting factor in determing the overall printing rate. If powder dispersion in a liquid vehicle is used, however, the layer must be at least partially dry prior to the ink-jet application of the binder material. The drying time will depend on the specific nature of the powder, binder, and solvent used.

The dimensions of the individual portions of the component being formed, sometimes referred to as the "feature" size thereof, is primarily dependent on the size of the binder droplets used, while the tolerance on such dimensions primarily depends on the degree of the reproducibility of the droplet spread characteristics of the binder material which is utilized.

Ink-jet printing of a liquid binder using currently known ink-jet devices can provide jet droplet sizes of as low as 15 microns, for example. It is possible that even smaller droplet sizes will be practical, with the lower limit on droplet size arising from surface energy considerations in the creation of new surface area and in the increased likelihood of the clogging of small jets.

Overall part tolerance will depend not only on drop spreading, but also on material shrinkage and the reproducibility of shrinkage characteristics as well. As an example, if the binder/powder combination shrinks by 1% and the shrinkage is reproducible to within 5% of its nominal value of 1%, an overall variation due to shrinkage can be approximately 0.0005 inches/inch. The actual shrinkage that occurs during binder curing or deposition is a relatively strong function of particle rearrangement. Dimensional tolerance and particle packing can be empirically determined for the best results in each case.

Alumina, zirconia, zircon (i.e., zirconium silicate), and silicon carbide are representative ceramic materials which can be bonded using the techniques of the invention. Both natural and synthetic dispersants are available for these materials in organic vehicles. For example, alumina is very effectively dispersed by glyceride surfactants in toluene/MEK solvents, as is used for casting thin sheets of particles in the production of dielectric substrates in the electronic packaging industry. Silicon carbide, for example, can be easily dispersed in hexane if small amounts of OLOA 1200 (as obtained, for example, from Chevron Chemical Co. Oronite Additives Div. of San Francisco, CaLifornia) are present. OLOA is primarily used as an additive in crank case oil where it acts as a dispersant for metal particles produced by engine wear.

Organic binders have been used in the ceramics industry and are typically polymeric resins obtained from a variety of sources. They can be either water soluble, such as celluosic binders, as used in extrusion technology, or they can be soluble in only volatile organic solvents, such as the butyral resins, as used in tape casting technology. The latter water soluble systems can be removed relatively quickly and seem particularly useful in the technique of the invention. Another type of organic binder would be a ceramic precursor material such as polycarbosilazane.

Inorganic binders are useful in cases where the binder is to be incorporated into the final component. Such binders are generally silicate based and are typically formed from the polymerization of silicic acid or its salts in aqueous solution. Another exemplary inorganic binder which can be used is TEOS (tetraethylorthosilicate). During drying, the colloidal silica aggregates at the necks of the matrix particles to form a cement-like bond. During firing, the silica flows and acts to rearrange the matrix particles through the action of surface tension forces and remains after firing. Soluble silicate materials have been used as binders in refractory castable materials, for example, and have the advantage, when used in the technique of the invention, of producing substantially the same type of molded refractory body that is used in the casting industry.

In some applications, it may be preferable that the binder harden relatively rapidly upon being deposited so that the next layer of particles placed on a surface of the previous layer is not subject to particle rearrangement due to capillary forces. Moreover, a hardened binder is not subject to contamination from solvents which may be used in powder deposition. In other cases, it may not be necessary that the binder be fully hardened between layers and a subsequent layer of powder particles may be deposited on a previous layer which is not yet fully hardened.

Where hardening occurs at the time the binder is deposited, thermal curing, i.e., evaporation of the binder carrier liquid, for such purpose would generally require that the component being formed be warmed as the printing of the binder material is performed, while the printhead itself is cooled so that unprinted binder material in the reservoir of the ink-jet head retains its desired properties. Such hardening can be achieved by heating the binder material indirectly, as by heating the overall apparatus in which the part is being formed using an appropriate external heat source, for example, or by heating the binder material directly as by applying hot air to the binder material or by applying infra-red energy or microwave energy thereto. Alternatively, a variety of thermally activated chemical reactions could also be used to harden the binder. For example, gelation of alkali silicate solutions can be made to occur by a change in pH accompanying the decomposition of organic reagents. Thus, a mixture of alkali silicate and formamide could be printed on to a hot component being formed. The rapid increase in temperature would greatly increase the formamide decomposition rate and, therefore, rapidly change the pH of the binder. Other thermally or chemically initiated techniques for hardening of the binder upon deposit thereof could be devised within the skill of those in the art.

While liquid and colloidal binder materials have been discussed above, in some applications binder material may be deposited in the form of binder particles entrained in a liquid. Such binder materials can be supplied via specially designed compound ink-jet structures capable of providing such entrained binder materials. An example of such a composite structure is discussed, for example, in the article "Ink-Jet Printing," J. Heinzle and C.H. Hertz, Advances In Electronics and Electron Physics, Vol. 65.

Moreover, in some applications in the fabrication of a part, the binder material which is used need not be a single binder material, but different binder materials can be used for different regions of the part being formed, the different materials being supplied by separate binder deposition heads. A dual head system is shown in FIG. 2 wherein a second head 43A is depicted in phantom therein at (B).

Many possible combinations of powder and binder materials can be selected in accordance with the invention. For example, ceramic powders or ceramic fibers can be used with either inorganic or organic binder materials or with a metallic binder material; a metal powder can be used with a metallic binder or a ceramic binder; and a plastic powder can be used with a solvent binder or a plastic binder, e.g., a low viscosity epoxy plastic material. Other appropriate combinations of powder and binder materials will occur to those in the art for various applications.

One useful application of the invention lies in the printing of molds for metal casting, particularly when the mold has a relatively complex configuration. Currently, complex, high precision castings are made by lost-wax casting, or investment casting. The process begins with the fabrication of an aluminum die which is used to mold wax positives of the part to be cast. The die is usually made by electric discharge machining. Wax positives are then made and connected together by hand with wax runner systems to form a tree. If the part is to have inter-

nal voids, a ceramic core is included in the wax positives. The tree is then dipped repeatedly into ceramic slurries with a drying cycle between each dipping operation. Following a final dry, th wax is melted and burned out of the shell mold and the mold is finally ready for casting. In its basic form, such lost-wax casting technique has long been used in the art.

With the technique of the invention, a ceramic shell mold can be fabricated directly to its final shape with no wax positives needed at all. The internal cavities can be fabricated by leaving the binder material out of these areas. The loose, unjointed powder will then wash out of the mold through the same passageways that will later admit molten metal in the final mold. FIGS. 7 and 8 show diagrammatic views of the formation of a part having reentrant features. Thus, in FIG. 7, the binder material is printed at three selected regions 20, 21 and 22 for an initial set of sequential layers, while, for a final set of sequential layers, the selected region 23 encompasses all three previously formed regions as shown in FIG. 8. For the printing of molds, typical powder materials, as discussed above, might include alumina, silica, zirconia, and zircon, for example. A typical binder would be colloidal silica. Moreover, the techniques of the invention can be used to form the cores only.

When making molds with core regions, it may be advantageous to use one particular binder material for the main body of the mold and a modified binder material in the core regions thereof, the depositing of the binder at the core regions requiring the use of a second printhead, for example. The technique of the invention has at least two advantages over lost-wax techniques for the creation of molds, one lying in the reduction in cost for small and moderate batches of parts and the other in the ability to produce a large variety of different molds and other parts with a relatively short turnaround time.

A relatively simple example of a system for performing the above powder distribution control operation and the nozzle control operation for the binder material is discussed with reference to the block diagram of FIG. 9 and the flow chart of FIG. 10. As seen in FIG. 9, a microcomputer 30 of any type which is usable for conventional computer-aided-design (CAD) operations, as would be well-known to the art, can be suitably programmed for the purpose of the invention. The microcomputer 30 is used to create a three-dimensional (3-D) model of the component to be made using well-known CAD techniques. An exemplary computerized 3-D model 50 is depicted in FIG. 11. A slicing algorithm is used to identify selected successive slices, i.e., to provide data with respect to selected 2-D layers, of the 3-D model 50 beginning at a bottom layer or slice thereof, for example. Exemplary layers 51 of the model 50 are depicted in the exploded view of FIG. 12. The development of a specific slicing algorithm for such purpose is well within the skill of those in the art.

Once a particular 2-D slice has been selected, the slice is then reduced to a series of one-dimensional (1-D) scan lines thereof as depicted in the plan view of FIG. 13. The development of a suitable reducing algorithm for such purpose would also be well within the skill of the art. Each of the scan lines 52 can comprise a single line segment (e.g., segment 53A of scan line 52A) or two or more shorter line segments, (e.g., segments 53B of scan line 52B), each line segment having a defined starting point on a scan line and a defined line segment length. For example, the line segments 53B have starting points at x_1 and x_2, respectively, as measured from a reference line 54, and lengths l_1 and l_2, respectively, as measured from their starting points x_1 and x_2.

The microcomputer 30 actuates the powder distribution operation when a particular 2-D slice of the 3-D model which has been created has been selected by supplying a powder "START" signal to a powder distribution controller circuit 31 which is used to actuate a powder distribution system 32 to permit a layer of powder for the selected slice to be deposited as by a powder head device in a suitable manner as discussed above. For example, the powder is deposited over the entire confined region within which the selected slice is located. Once the powder is distributed, the operation of powder distribution controller is stopped when the microcomputer 30 issues a powder "STOP" signal signifying that powder distribution over such region has been completed.

Microcomputer 30 then selects a scan line, i.e., the first scan line of the selected 2-D slice and then selects a line segment, e.g., the first 1-D line segment of the selected scan line and supplies data defining the starting point thereof and the length thereof to a binder jet nozzle control circuit 33. For simplicity in describing the operation it is assumed that a single binder jet nozzle is used and that such nozzle scans the line segments of a slice in a manner such that the overall 2-D slice is scanned in a conventional raster scan (X-Y) operation. When the real time position of the nozzle is at the starting point of the selected line segment, the nozzle 35 is turned on at the start of the line segment and is turned off at the end of the line segment in accordance with the defined starting point and length data supplied from computer 30 for that line segment. Each successive line segment is similarly scanned for the selected scan line and for each successive scan line of the selected slice in the same manner. For such purpose, the nozzle carrier system starts its motion with a scan "BEGIN" signal from microcomputer 30 so that it is moved both in the X axis (the "fast" axis) direction and in the Y axis (the "slow" axis) direction. Data as to the real time position of the nozzle carrier (and, hence, the nozzle) is supplied to the nozzle control circuit. When the complete slice has been scanned, a scan "STOP" signal signifies an end of the slice scan condition.

As each line segment is scanned, a determination is made as to whether nozzle operation has occurred for all line segments of a particular scan line of the selected slice. If not, the next line segment is scanned and the nozzle control operation for that line segment is performed. When nozzle operation for the final line segment

of a particular scan line has been completed, a determination is made as to whether the scan line involved is the final scan line of the selected slice. If not, the next scan line is selected and the scanning and nozzle control process for each successive line segment of such scan line of the slice is performed. When nozzle operation for the final scan line of a particular slice has been completed, a determination is then made as to whether such slice is the final slice of the overall 3-D model. If not, the next slice is selected and the overall process for each line segment of such scan line thereof is rejected, including the powder deposition and nozzle binder deposition required for all the scan lines thereof. When the binder material has been supplied the final slice of the 3-D model, the operation is completed.

The necessary programming required to implement the flow chart of FIG. 10 using the components of FIG. 9 would be well within the skill of the art and need not be discussed in further detail. Such an approach can be used for a single nozzle as described above and can be readily adapted for use with a binder head having multiple nozzles, e.g., an array of nozzles for providing an effective linear deposition of binder material, or a plurality of relatively shorter, multiple arrays thereof.

In addition to the above discussed embodiments of the invention, further variations or modifications of the techniques disclosed above will occur to those in the art. For example, the binder, rather than being applied in a wet state, can be applied in a dry state using materials having a low melting point so that, when applied and heated, the melted material penetrates the powder particles and when hardened bonds them together. Further, two or more different types of powder particles can be applied via two or more separate powder dispersion heads so as to deposit the different powders at different regions of the part being formed. The powder at such regions can then be bonded using the same or different binder materials so that different physical characteristics can be obtained at such different regions. Other modifications or extensions of the invention may occur to those in the art within the scope thereof. Hence, the invention is not to be construed as limited to the specific embodiments described above, except as defined by the appended claims.

Claims

1. A process for making a component comprising the steps of:

   a) depositing a layer of particulate material in a confined region (Fig. 2(A));
   b) causing said layer of particulate material to become bonded at one or more selected regions (Fig. 2(B));
   c) repeating steps a) and b) a selected number of times to produce a selected number of successive layers (Fig. 2(C) and (D)); and
   d) removing particulate material which is not at said one or more selected regions to provide the component (Fig. 2(E));

   characterized in that a binder material is applied to selected regions of a porous layer of particulate material, and that the binder bonds the particulate material in the said selected regions and causes successive layers to become bonded to each other.

2. A process in accordance with claim 1 wherein deposition of the particulate material applied two or more different types of particulate material at different regions of the component being formed.

3. A process in accordance with claim 1 or 2 wherein said particulate material is a ceramic, metallic, or plastic material and said binder material is an inorganic material, an organic material, or a metallic material.

4. A process in accordance with claim 1 or 3 wherein said particulate material is a ceramic and said binder material is a colloidal suspension of ceramic particles.

5. A process in accordance with claim 1 or 2 wherein said particulate material is a ceramic powder or ceramic fiber and said binder material is an inorganic ceramic material, an organic ceramic precursor material, or a metallic material.

6. A process in accordance with claim 1 or 2 wherein said particulate material is a metal powder and said binder material is a metallic or a ceramic material.

7. A process in accordance with claims 1 or 2 wherein said particulate material is a plastic material and said binder material is a solvent for said plastic material.

8. A process in accordance with any of claims 1 to 7 including the step of further processing by heating or curing said bonded material to improve the properties of the finished component.

9. A process in accordance with claim 8 wherein said further processing includes the step of heating said selected number of successive layers of bonded material to further strengthen the bonding of said successive layers of bonded material.

10. A process in accordance with any of claims 1 to 9 wherein said particulate material is deposited in a dry state.

11. A process in accordance with claim 10 and further including the step of vibrating the dry particulate

material to settle said material as said layers thereof are deposited (Figs. 3-5).

12. A process in accordance with claim 11 wherein said vibrating is performed by mechanical vibration of said deposited particulate material (Fig. 3), by applying acoustic energy to said deposited particulate material (Fig. 4), or by applying a piezoelectric scraper device to said deposited particulate material (Fig. 5).

13. A process in accordance with any of claims 1 to 9 wherein said particulate material is deposited in a liquid vehicle and further including the step of at least partially drying the particulate material before applying said binder material.

14. A process in accordance with claim 13 wherein said at least partial drying is performed by applying infrared or hot air heat to said deposited layer of particulate material or by applying microwaves to said deposited layer of particulate material.

15. A process in accordance with any of claims 10 to 14 wherein the porosity of said component is determined in accordance with the packing density of said particulate material.

16. A process in accordance with any of claims 1 to 15 wherein said binder material is applied as a liquid.

17. A process in accordance with claim 16 wherein said liquid is an aqueous solution or a colloidal suspension.

18. A process in accordance with claim 17 wherein said liquid comprises binder particles entrained in a carrier liquid.

19. A process in accordance with any of claims 1 to 18 wherein said binder material comprises at least two different binder materials, said two different binder materials being applied to at least two different selected regions of said particulate material (Fig. 2(B)).

20. A process in accordance with any of claims 1 to 19 wherein said binder material is applied as one or more jet streams thereof.

21. A process in accordance with claim 20 wherein each of said one or more jet streams of binder material is applied as a continuous jet stream thereof.

22. A process in accordance with claim 20 where each of said one or more jet streams is applied as a plurality of separate droplets thereof.

23. A process in accordance with claim 20, 21 or 22 wherein said binder material is applied as a single jet stream.

24. A process in accordance with claims 20, 21 or 22 wherein a plurality of jet streams are applied in one or more linear arrays thereof (Fig. 1).

25. A process in accordance with any of claims 1 to 24 wherein said binder material is at least partially hardened after being applied.

26. A process in accordance with claim 25 wherein said binder material is hardened by applying heat energy thereto.

27. A process in accordance with claim 26 wherein said heat energy is applied as infra-red or microwave heat energy.

28. A process in accordance with claim 27 wherein said binder material is hardened by chemical reaction.

29. A process in accordance with claim 28 wherein the particles of said particulate material are covered with a coating material and said chemical reaction occurs between said binder material and said coating material.

30. A process in accordance with claim 28 wherein said particulate material is deposited in a wet state and said chemical reaction occurs between said binder material and the liquid in said wet powdered material.

31. A process in accordance with claim 28 including the step of supplying a gaseous material to said binder material, said binder material chemically reacting with said gaseous material to form a partially hardened binder material.

32. A process in accordance with any of claims 1 to 31 wherein said material which is removed is removed ultrasonically.

33. A process in accordance with any of claims 1 to 32 for making a mold having re-entrant regions and one or more passageways for the admission of molding material into said mold, wherein said binder material is not applied to said re-entrant regions and unbonded particulate material is removed from said re-entrant regions via said passageways (Figs. 7, 8).

34. A process in accordance with claim 33 when said powder material is a ceramic powder material for forming a ceramic mold.

35. A process in accordance with claim 33 wherein said mold comprises a main body region and core

regions, one type of further material being applied to form said main body region and a different type of further material being applied to form said core regions.

36. A process in accordance with any of claims 1 to 32 wherein said component is a mold.

37. A system for making a component, comprising:
means (13) for depositing a selected number of successive porous layers of a particulate material;
means (15) for causing the particulate material to become bonded at one or more selected regions in each layer to form said component; and
means for removing particulate material which is not at said one or more selected regions;
characterized in that the means (15) for causing the particulate material to become bonded comprises means for applying a binder material to said selected regions of each successive layer after each successive layer has been deposited.

38. A system in accordance with claim 37 wherein said binder material applying means (15) includes means (43) for applying said material as one or more jet streams thereof.

39. A system in accordance with claim 37 and further including means for further processing by heating or curing said bonded material to improve the properties of the finished component.

40. A system in accordance with claim 39 wherein said means for further processing includes means for heating said bonded material to further strengthen the bonding of said bonded material.

41. A system in accordance with claim 37 wherein said particulate material depositing means (13) deposits said material as a powder material in a dry state.

42. A system in accordance with claim 41 and further including means (61) for mechanically vibrating said dry deposited powder material, for applying acoustic energy (63) to said deposited powder material or for applying a piezoelectric scraper device (65) to said deposited powder material.

43. A system in accordance with claim 39 wherein said particulate material depositing means (13) deposits said material as a powder material in a liquid state.

44. A system in accordance with claim 43 and further including means for at least partially drying the powder material before applying further material.

45. A system in accordance with claim 44 wherein said drying means includes means for applying infra-red or hot air heat to said deposited layer of powder material or for applying microwaves to said deposited layer of powder material.

46. A system in accordance with any of claims 37 to 45 and further including means for at least partially hardening said binder material.

47. A system in accordance with claim 46 wherein said hardening means includes means for applying heat energy to said binder material.

48. A system in accordance with any of claims 37 to 47 wherein said binder material applying means (43, 43A) applies two different types of binder materials to different regions of said layers of particulate material.

49. A system in accordance with claim 37 wherein said binder material applying means (15) applies said material using a continuous jet means or a drop-on-demand jet means.

50. A system in accordance with claim 37 wherein said binder material applying means (15) is arranged to provide a relative movement of said applying means with respect to said successive layers of particulate material.

51. A system in accordance with claim 37 wherein said binder material applying means (15) is moved over said successive layers of particulate material in a selected pattern, said successive layers of particulate material being maintained stationary.

52. A system in accordance with claim 37 wherein said binder material applying means (15) is moved over said successive layers of particulate material in a raster scan pattern (Fig. 9).

53. A system in accordance with claim 37 and further including;
a chamber (72);
a piston (70) movable in said chamber, said depositing means (13) depositing said successive layers of particulate material within a region defined by the chamber and the piston; and
means for moving said piston downwardly in said chamber after the depositing of each successive layer of particulate material.

Patentansprüche

1. Verfahren zur Herstellung eines Bauteils, umfassend die Schritte:

(a) Ablagern einer Schicht von Partikelmaterial in einem begrenzten Bereich (Fig. 2(A));

(b) Veranlassen, daß die Schicht von Partikelmaterial in einem oder mehreren ausgewählten Bereichen verbunden wird (Fig. 2(B));

(c) Wiederholen der Schritte (a) und (b) eine ausgewählte Anzahl von Malen, um eine ausgewählte Anzahl von aufeinanderfolgenden Schichten herzustellen (Fig. 2(C) und (D)); und

(d) Entfernen von Partikelmaterial, das nicht in diesem einen oder mehreren Bereichen ist, um das Bauteil zu schaffen (Fig. 2(E));

dadurch gekennzeichnet, daß ein Bindermaterial auf ausgewählte Bereiche einer porösen Schicht von Partikelmaterial aufgetragen wird und daß der Binder das Partikelmaterial in den ausgewählten Bereichen bindet und verursacht, daß aufeinanderfolgende Schichten miteinander verbunden werden.

2. Verfahren nach Anspruch 1, bei welchem bei dem Ablagern des Partikelmaterials, das aufgetragen wird, zwei oder mehr verschiedene Arten von Partikelmaterial in unterschiedlichen Bereichen des Bauteils, das geformt wird, aufgetragen werden.

3. Verfahren nach Anspruch 1 oder 2, bei welchem das Partikelmaterial ein Keramik-, Metall- oder Kunststoffmaterial ist und das Bindermaterial ein anorganisches Material, ein organisches Material oder ein metallisches Material ist.

4. Verfahren nach Anspruch 1 oder 3, bei welchem das Partikelmaterial ein Keramikmaterial ist und das Bindermaterial eine kolloidale Suspension von Keramikpartikeln ist.

5. Verfahren nach Anspruch 1 oder 2, bei welchem das Partikelmaterial ein Keramikpulver oder Keramikfasern ist und das Bindermaterial ein anorganisches Keramikmaterial, ein organisches Keramikvorläufermaterial oder ein metallisches Material ist.

6. Verfahren nach Anspruch 1 oder 2, bei welchem das Partikelmaterial ein Metallpulver ist und das Bindermaterial ein metallisches oder keramisches Material ist.

7. Verfahren nach Anspruch 1 oder 2, bei welchem das Partikelmaterial ein Kunststoffmaterial ist und das Bindermaterial ein Lösungsmittel für das Kunststoffmaterial ist.

8. Verfahren nach einem der Ansprüch 1 bis 7, enthaltend den Schritt der weiteren Verarbeitung des gebundenen Materials durch Erwärmen oder Härten, um die Eigenschaften des fertiggestellten Bauteils zu verbessern.

9. Verfahren nach Anspruch 8, bei welchem die Weiterbearbeitung den Schritt des Erwärmens der ausgewählten Zahl von aufeinanderfolgenden Schichten von gebundenem Material zur weiteren Festigung der Verbindung der aufeinanderfolgenden Schichten von gebundenem Material enthält.

10. Verfahren nach einem der Ansprüche 1 bis 9, bei welchem das Partikelmaterial in trockenem Zustand abgelagert wird.

11. Verfahren nach Anspruch 10 und weiter enthaltend den Schritt des Rüttelns des trockenen Partikelmaterials, um das Material zu setzen, wenn die Schichten desselben abgelagert werden (Fig. 3 bis 5).

12. Verfahren nach Anspruch 11, bei welchem das Rütteln durch mechanische Vibration des abgelagerten Partikelmaterials (Fig. 3), durch Anwenden von akustischer Energie auf das abgelagerte Partikelmaterial (Fig. 4) oder durch Anwenden einer piezoelektrischen Abstreifeinrichtung auf das abgelagerte Partikelmaterial (Fig. 5) ausgeführt wird.

13. Verfahren nach einem der Ansprüche 1 bis 9, bei welchem das Partikelmaterial in einem flüssigen Trägerstoff abgelagert wird und ferner enthaltend den Schritt der wenigstens teilweisen Trocknung des Partikelmaterials vor dem Auftragen des Bindermaterials.

14. Verfahren nach Anspruch 13, bei welchem die wenigstens teilweise Trocknung durch Anwenden von Infrarot- oder Warmluftwärme auf die abgelagerte Schicht von Partikelmaterial oder durch Anwenden von Mikrowellen auf die abgelagerte Schicht von Partikelmaterial durchgeführt wird.

15. Verfahren nach einem der Ansprüche 10 bis 14, bei welchem die Porosität des Bauteils in Übereinstimmung mit der Packungsdichte des Partikelmaterials bestimmt wird.

16. Verfahren nach einem der Ansprüche 1 bis 15, bei welchem das Bindermaterial als eine Flüssigkeit aufgetragen wird.

17. Verfahren nach Anspruch 16, bei welchem die Flüssigkeit eine wässerige Lösung oder eine kolloidale Suspension ist.

18. Verfahren nach Anspruch 17, bei welchem die Flüssigkeit Binderpartikel umfaßt, die in einer Trägerflüssigkeit mitgerissen werden.

19. Verfahren nach einem der Ansprüche 1 bis 18, bei welchem das Bindermaterial wenigstens zwei verschiedene Bindermaterialien umfaßt, welche zwei verschiedenen Bindermaterialien auf wenigstens

zwei verschiedene ausgewählte Bereiche des Partikelmaterials aufgetragen werden (Fig. 2(B)).

20. Verfahren nach einem der Ansprüche 1 bis 19, bei welchem das Bindermaterial als ein oder mehrere Strahlströme desselben aufgetragen wird.

21. Verfahren nach Anspruch 20, bei welchem der Strahlstrom oder jeder der mehreren Strahlströme des Bindermaterials als ein kontinuierlicher Strahlstrom desselben aufgetragen wird.

22. Verfahren nach Anspruch 20, bei welchem der Strahlstrom oder jeder der mehreren Strahlströme als eine Vielzahl von getrennten Tröpfchen desselben aufgetragen wird.

23. Verfahren nach Anspruch 20, 21 oder 22, bei welchem das Bindermaterial als ein einzelner Strahlstrom aufgetragen wird.

24. Verfahren nach Anspruch 20, 21 oder 22, bei welchem eine Vielzahl von Strahlströmen in einer oder mehreren linearen Anordnungen derselben aufgetragen werden (Fig. 1).

25. Verfahren nach einem der Ansprüche 1 bis 24, bei welchem das Bindermaterial wenigstens teilweise nach dem Auftragen gehärtet wird.

26. Verfahren nach Anspruch 25, bei welchem das Bindermaterial durch Einwirken von Wärmeenergie auf dieses gehärtet wird.

27. Verfahren nach Anspruch 26, bei welchem die Wärmeenergie als Infrarot- oder Mikrowellenwärmeenergie angewendet wird.

28. Verfahren nach Anspruch 27, bei welchem das Bindermaterial durch chemische Reaktion gehärtet wird.

29. Verfahren nach Anspruch 28, bei welchem die Partikel des Partikelmaterials mit einem Beschichtungsmaterial bedeckt sind und die chemische Reaktion zwischen dem Bindermaterial und dem Beschichtungsmaterial auftritt.

30. Verfahren nach Anspruch 28, bei welchem das Partikelmaterial in einem nassen Zustand abgelagert wird und die chemische Reaktion zwischen dem Bindermaterial und der Flüssigkeit in dem nassen pulverförmigen Material auftritt.

31. Verfahren nach Anspruch 28, das den Schritt der Zufuhr eines gasförmigen Materials zu dem Bindermaterial enthält, welches Bindermaterial chemisch mit dem gasförmigen Material reagiert, um ein teilweise gehärtetes Bindermaterial zu bilden.

32. Verfahren nach einem der Ansprüche 1 bis 31, bei welchem das Material, das entfernt wird, mittels Ultraschall entfernt wird.

33. Verfahren nach einem der Ansprüche 1 bis 32 zur Herstellung einer Form, die Rückeintrittsbereiche und einen oder mehrere Kanäle zur Zufuhr von Formmaterial in die Form aufweist, bei welchem das Bindermaterial nicht auf die Rückeintrittsbereiche aufgetragen wird und nicht gebundenes Partikelmaterial von den Rückeintrittsbereichen durch die Kanäle entfernt wird (Fig. 7, 8).

34. Verfahren nach Anspruch 33, bei welchem das Pulvermaterial ein keramisches Pulvermaterial zur Bildung einer keramischen Form ist.

35. Verfahren nach Anspruch 33, bei welchem die Form einen Hauptkörperbereich und Kernbereiche umfaßt, wobei eine Art von weiterem Material aufgetragen wird, um den Hauptkörperbereich zu bilden und eine unterschiedliche Art von weiterem Material aufgetragen wird, um die Kernbereiche zu bilden.

36. Verfahren nach einem der Ansprüche 1 bis 32, bei welchem das Bauteil eine Form ist.

37. System zur Herstellung eines Bauteils, umfassend:
eine Einrichtung (13) zum Ablagern einer ausgewählten Anzahl von aufeinanderfolgenden porösen Schichten eines Partikelmaterials;
eine Einrichtung (15), um zu veranlassen, daß das Partikelmaterial in einem oder in mehreren ausgewählten Bereichen in jeder Schicht gebunden wird, um das Bauteil zu bilden; und
eine Einrichtung zum Entfernen des Partikelmaterials, das nicht in dem einen oder den mehreren ausgewählten Bereichen ist;
dadurch gekennzeichnet, daß die Einrichtung (15) zum Veranlassen, daß das Partikelmaterial gebunden wird, eine Einrichtung zum Auftragen eines Bindermaterials auf die ausgewählten Bereiche jeder der aufeinanderfolgenden Schichten umfaßt, nachdem jede der aufeinanderfolgenden Schichten abgelagert wurde.

38. System nach Anspruch 37, bei welchem die Auftrageinrichtung für das Bindermaterial (15) eine Einrichtung (43) zum Auftragen des Materials als ein oder mehrere Strahlströme desselben einschließt.

39. System nach Anspruch 37 und weiter enthaltend eine Einrichtung zur weiteren Bearbeitung des gebundenen Materials durch Erwärmen oder Härten, um die Eigenschaften der fertiggestellten Bauteils zu verbessern.

40. System nach Anspruch 39, bei welchem die Einrichtung zur weiteren Bearbeitung eine Einrichtung zum Erwärmen des gebundenen Materials enthält, um weiter die Bindung des gebundenen Materials zu festigen.

41. System nach Anspruch 37, bei welchem die Einrichtung (13) zum Ablagern von Partikelmaterial das Material als ein Pulvermaterial in trockenem Zustand ablagert.

42. System nach Anspruch 41 und weiter enthaltend eine Einrichtung (61) zum mechanischen Rütteln des trocken abgelagerten Pulvermaterials, zum Anwenden von akustischer Energie (63) auf das abgelagerte Pulvermaterial oder zum Anwenden einer piezoelektrischen Abstreifeinrichtung (65) auf das abgelagerte Pulvermaterial.

43. System nach Anspruch 39, bei welchem die Einrichtung (13) zum Ablagern von Partikelmaterial das Material als Pulvermaterial in einem flüssigen Zustand ablagert.

44. System nach Anspruch 43 und weiter enthaltend eine Einrichtung zum wenigstens teilweisen Trocknen des Pulvermaterials vor dem Auftragen von weiterem Material.

45. System nach Anspruch 44, bei welchem die Einrichtung zum Trocknen eine Einrichtung zum Anwenden von Infrarot- oder Warmluftwärme auf die abgelagerte Schicht von Pulvermaterial oder zum Anwenden von Mikrowellen auf die abgelagerte Schicht von Pulvermaterial enthält.

46. System nach einem der Ansprüche 37 bis 45 und weiter enthaltend eine Einrichtung zum wenigstens teilweisen Härten des Bindermaterials.

47. System nach Anspruch 46, bei welchem die Einrichtung zum Härten eine Einrichtung zum Anwenden von Wärmeenergie auf das Bindermaterial enthält.

48. System nach einem der Ansprüche 37 bis 47, bei welchem die Einrichtung (43, 43A) zum Auftragen von Bindermaterial zwei verschiedene Arten von Bindermaterialien auf verschiedene Bereiche der Schichten von Partikelmaterial aufträgt.

49. System nach Anspruch 37, bei welchem die Einrichtung (15) zum Auftragen von Bindermaterial das Material unter Verwendung einer kontinuierlichen Strahleinrichtung oder einer Strahleinrichtung nach dem Tropfen-nach-Bedarf-Prinzip verwendet.

50. System nach Anspruch 37, bei welchem die Einrichtung (15) zum Auftragen von Bindermaterial so angeordnet ist, daß sie eine Relativbewegung der Auftrageinrichtung bezüglich der aufeinanderfolgenden Schichten von Partikelmaterial ermöglicht.

51. System nach Anspruch 37, bei welchem die Einrichtung (15) zum Auftragen von Bindermaterial über die aufeinanderfolgenden Schichten von Partikelmaterial in einem ausgewählten Muster bewegt wird, welche aufeinanderfolgenden Schichten von Partikelmaterial stationär gehalten werden.

52. System nach Anspruch 37, bei welchem die Einrichtung (15) zum Auftragen von Bindermaterial über die aufeinanderfolgenden Schichten von Partikelmaterial in einem Rasterabtastmuster (Fig. 9) bewegt wird.

53. System nach Anspruch 37 und weiter enthaltend:
eine Kammer (72);
einen Kolben (70), der in der Kammer beweglich ist, wobei die Einrichtung (13) zum Ablagern die aufeinanderfolgenden Schichten von Partikelmaterial innerhalb eines Bereiches ablagert, der durch die Kammer und den Kolben definiert ist; und
eine Einrichtung zum Bewegen des Kolbens abwärts in der Kammer nach der Ablagerung jeder aufeinanderfolgenden Schicht von Partikelmaterial.

Revendications

1. Procédé pour fabriquer un composant, comprenant les étapes consistant à :

   a) déposer une couche d'une matière particulaire dans une région confinée (figure 2(A)) ;
   b) déterminer la liaison de ladite couche de matière particulaire dans une ou plusieurs régions choisies (figure 2(B)) ;
   c) répéter les étapes a) et b) un nombre de fois choisi pour produire un nombre choisi de couches successives (figure 2(C) et (D)) ; et
   d) éliminer la matière particulaire qui ne se trouve pas dans ladite ou lesdites région(s) choisie(s) pour fournir le composant (figure 2(E)) ;

   caractérisé en ce qu'on applique une matière liante à des régions choisies d'une couche poreuse de matière particulaire et en ce que le liant lie la matière particulaire dans lesdites régions choisies et détermine la liaison des couches successives les unes aux autres.

2. Procédé selon la revendication 1, dans lequel le dépôt de matière particulaire a déposé deux types différents ou plus de matière particulaire dans différentes régions du composant formé.

3. Procédé selon la revendication 1 ou 2, dans lequel ladite matière particulaire est une matière

céramique, métallique ou plastique, et ladite matière liante est une matière inorganique, une matière organique ou une matière métallique.

4. Procédé selon la revendication 1 ou 3, dans lequel ladite matière particulaire est une matière céramique et ladite matière liante est une suspension colloïdale de particules céramiques.

5. Procédé selon la revendication 1 ou 2, dans lequel ladite matière particulaire est une poudre céramique ou une fibre céramique et ladite matière liante est une matière céramique inorganique, une matière précurseur de céramique organique, ou une matière métallique.

6. Procédé selon la revendication 1 ou 2, dans lequel ladite matière particulaire est une poudre métallique et ladite matière liante est une matière métallique ou une matière céramique.

7. Procédé selon la revendication 1 ou 2, dans lequel ladite matière particulaire est une matière plastique et ladite matière liante est un solvant pour la matière plastique.

8. Procédé selon l'une quelconque des revendications 1 à 7, comprenant l'étape de traitement additionnel de ladite matière liée par chauffage ou durcissement pour améliorer les propriétés du composant fini.

9. Procédé selon la revendication 8, dans lequel ledit traitement additionnel comprend l'étape consistant à chauffer ledit nombre choisi de couches successives de matière liée pour renforcer davantage la liaison desdites couches successives de matière liée.

10. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel ladite matière particulaire est déposée à l'état sec.

11. Procédé selon la revendication 10 et comprenant en outre l'étape consistant à faire vibrer la matière particulaire sèche pour tasser ladite matière au fur et à mesure que lesdites couches de cette matière sont déposées (figures 3-5).

12. Procédé selon la revendication 11, dans lequel ledit vibrage est exécuté par un vibrage mécanique de ladite matière particulaire déposée (figure 3), ou en appliquant une énergie acoustique à ladite matière particulaire déposée (figure 4) ou en faisant agir un dispositif racleur piézoélectrique sur ladite matière particulaire déposée (figure 5).

13. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel ladite matière particulaire est déposée dans un véhicule liquide et comprend en outre l'étape consistant à sécher au moins partiellement la matière particulaire avant d'apporter la matière liante.

14. Procédé selon la revendication 13, dans lequel ledit séchage au moins partiel est exécuté en appliquant de la chaleur par rayons infrarouges ou par air chaud à ladite couche déposée de matière particulaire ou en faisant agir des micro-ondes sur ladite couche déposée de matière particulaire.

15. Procédé selon l'une quelconque des revendications 10 à 14, dans lequel la porosité dudit composant est déterminée en fonction de la densité de tassement de ladite matière particulaire.

16. Procédé selon l'une quelconque des revendications 1 à 15, dans lequel ladite matière liante est apportée sous la forme d'un liquide.

17. Procédé selon la revendication 16, dans lequel ledit liquide est une solution aqueuse ou une suspension colloïdale.

18. Procédé selon la revendication 17, dans lequel ledit liquide comprend des particules de liant entraînées dans un liquide porteur.

19. Procédé selon l'une quelconque des revendications 1 à 18, dans lequel ladite matière liante comprend au moins deux matières liantes différentes, lesdites deux matières liantes différentes étant appliquées à au moins deux régions choisies différentes de ladite matière particulaire (figure 2(B)).

20. Procédé selon l'une quelconque des revendications 1 à 19, dans lequel ladite matière liante est appliquée sous la forme d'un ou plusieurs courants projetés de celle-ci.

21. Procédé selon la revendication 20, dans lequel chacun desdits un ou plusieurs courant(s) projeté(s) de matière liante est appliqué sous la forme d'un courant projeté continu de celle-ci.

22. Procédé selon la revendication 20, où chacun desdits un ou plusieurs courant(s) projeté(s) est appliqué sous la forme d'une pluralité de gouttelettes distinctes de celui-ci.

23. Procédé selon les revendications 20, 21 ou 22, dans lequel ladite matière liante est appliquée sous la forme d'un unique courant projeté.

24. Procédé selon les revendications 20, 21 ou 22, dans lequel une pluralité de courants projetés sont appliqués en un ou plusieurs groupe(s) linéaire(s) de tels courants projetés (figure 1).

25. Procédé selon l'une des revendications 1 à 24, dans lequel ladite matière liante est au moins partiellement durcie après avoir été appliquée.

26. Procédé selon la revendication 25, dans lequel ladite matière liante est durcie par application d'énergie thermique à cette matière.

27. Procédé selon la revendication 26, dans lequel ladite énergie thermique est appliquée sous la forme d'énergie thermique infrarouge ou à micro-ondes.

28. Procédé selon la revendication 27, dans lequel ladite matière liante est durcie par une réaction chimique.

29. Procédé selon la revendication 28, dans lequel les particules de ladite matière particulaire sont recouvertes d'une matière de revêtement et ladite réaction chimique se produit entre ladite matière liante et ladite matière de revêtement.

30. Procédé selon la revendication 28, dans lequel ladite matière particulaire est déposée à l'état humide et ladite réaction chimique se produit entre ladite matière liante et le liquide contenu dans ladite matière en poudre humide.

31. Procédé selon la revendication 28, comprenant l'étape consistant à acheminer une matière gazeuse à ladite matière liante, ladite matière liante réagissant chimiquement avec ladite matière gazeuse pour former une matière liante partiellement durcie.

32. Procédé selon l'une quelconque des revendications 1 à 31, dans lequel ladite matière qui est éliminée est éliminée par ultrasons.

33. Procédé selon l'une quelconque des revendications 1 à 32, destiné à la fabrication d'un moule ayant des régions rentrantes et un ou plusieurs passages destinés à l'admission d'une matière à mouler dans ledit moule, dans lequel ladite matière liante n'est pas appliquée auxdites régions rentrantes et la matière particulaire non liée est éliminée desdites régions rentrantes en passant par lesdits passages (figures 7, 8).

34. Procédé selon la revendication 33, dans lequel ladite matière en poudre est une matière en poudre céramique destinée à former un moule céramique.

35. Procédé selon la revendication 33, dans lequel ledit moule comprend une région de corps principal et des régions de noyaux, un type de matière additionnelle étant appliqué pour former ladite région de corps principal et un type différent de matière additionnelle étant appliqué pour former lesdites régions de noyaux.

36. Procédé selon l'une quelconque des revendications 1 à 32, dans lequel ledit composant est un moule.

37. Système pour produire un composant comprenant :

des moyens (13) destinés à déposer un nombre choisi de couches poreuses successives d'une matière particulaire ;

des moyens (15) destinés à causer la liaison de la matière particulaire dans une ou plusieurs régions choisies dans chaque couche pour former ledit composant ; et

des moyens destinés à éliminer la matière particulaire qui ne se trouve pas dans ladite ou lesdites plusieurs régions choisies ;

caractérisé en ce que les moyens (15) destinés à causer la liaison de la matière particulaire comprennent des moyens destinés à appliquer une matière liante auxdites régions choisies de chaque couche successive après que chaque couche successive a été déposée.

38. Système selon la revendication 37, dans lequel lesdites moyens (15) d'application de matière liante comprennent des moyens (43) destinés à appliquer ladite matière sous la forme d'un ou plusieurs courant(s) projeté(s) de celle-ci.

39. Système selon la revendication 37 et comprenant en outre des moyens destinés à appliquer un traitement additionnel en chauffant ou en durcissant ladite matière liée pour améliorer les propriétés du composant fini.

40. Système selon la revendication 39, dans lequel lesdits moyens destinés à appliquer un traitement additionnel, comprennent des moyens destinés à chauffer ladite matière liée pour renforcer davantage la liaison de ladite matière liée.

41. Système selon la revendication 37, dans lequel lesdits moyens (13) de dépôt de la matière particulaire déposent ladite matière sous la forme d'une poudre à l'état sec.

42. Système selon la revendication 41 et comprenant en outre des moyens (61) destinés à faire vibrer mécaniquement ladite matière en poudre déposée sèche, à appliquer une énergie acoustique (63) à ladite matière en poudre déposée ou à faire agir un dispositif racleur piézoélectrique (65) sur ladite matière en poudre déposée.

43. Système selon la revendication 39, dans lequel lesdits moyens (13) de dépôt de la matière particulaire déposent ladite matière sous la forme d'une matière en poudre dans un état liquide.

44. Système selon la revendication 43 et comprenant en outre des moyens destinés à sécher au moins par-

tiellement la matière en poudre avant d'appliquer une nouvelle quantité de matière.

45. Système selon la revendication 44, dans lequel lesdits moyens de séchage comprennent des moyens destinés à appliquer de la chaleur par rayons infrarouges ou par air chaud à ladite couche déposée de matière en poudre, ou à appliquer des micro-ondes sur ladite couche déposée de matière en poudre.

46. Système selon l'une quelconque des revendications 37 à 45, et comprenant en outre des moyens destinés à durcir au moins partiellement ladite matière liante.

47. Système selon la revendication 46, dans lequel lesdits moyens de durcissement comprennent des moyens destinés à appliquer de l'énergie thermique à ladite matière liante.

48. Système selon l'une quelconque des revendications 37 à 47, dans lequel lesdits moyens (43, 43A) d'application de matière liante apportent deux types différents de matières liantes à différentes régions desdites couches de matières particulaire.

49. Système selon la revendication 37, dans lequel lesdits moyens (15) d'application de matière liante appliquent ladite matière en utilisant des moyens à jet continu ou des moyens à jet à gouttes à la demande.

50. Système selon la revendication 37, dans lequel lesdits moyens (15) d'application de matière liante sont agencés pour déterminer un déplacement relatif desdits moyens d'application par rapport auxdites couches successives de matière particulaire.

51. Système selon la revendication 37, dans lequel lesdits moyens (15) d'application de matière liante se déplacent au-dessus desdites couches successives de matière particulaire selon un circuit choisi, lesdites couches successives de matière particulaire étant maintenues immobiles.

52. Système selon la revendication 37, dans lequel lesdits moyens (15) d'application de la matière liante se déplacent au-dessus desdites couches successives de matière particulaire en suivant un circuit de balayage à trame (figure 9).

53. Système selon la revendication 37 et comprenant en outre :

une chambre (72) ;

un piston (70) qui peut se déplacer dans ladite chambre, lesdits moyens de dépôt (13) déposant lesdites couches successives de matière particulaire dans une région définie par la chambre et le piston ; et

des moyens destinés à faire descendre le piston dans ladite chambre après le dépôt de chaque couche successive de matière particulaire.

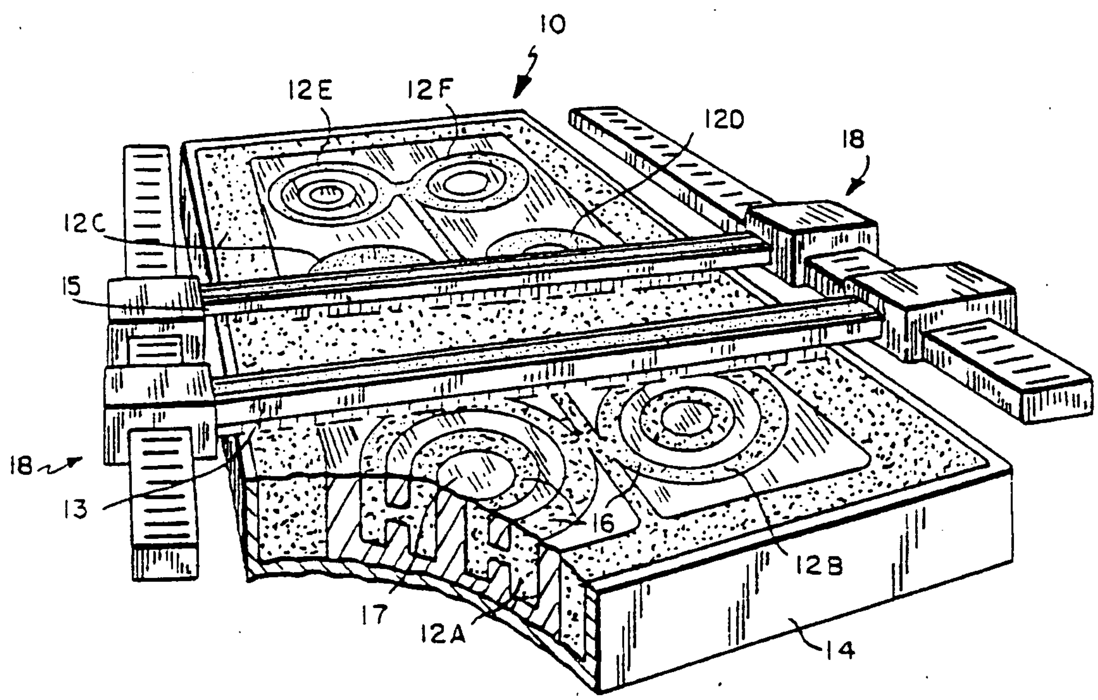


FIG. 1

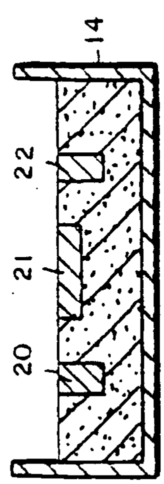


FIG.7

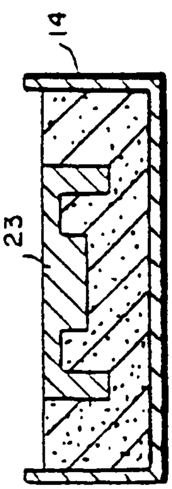


FIG.8

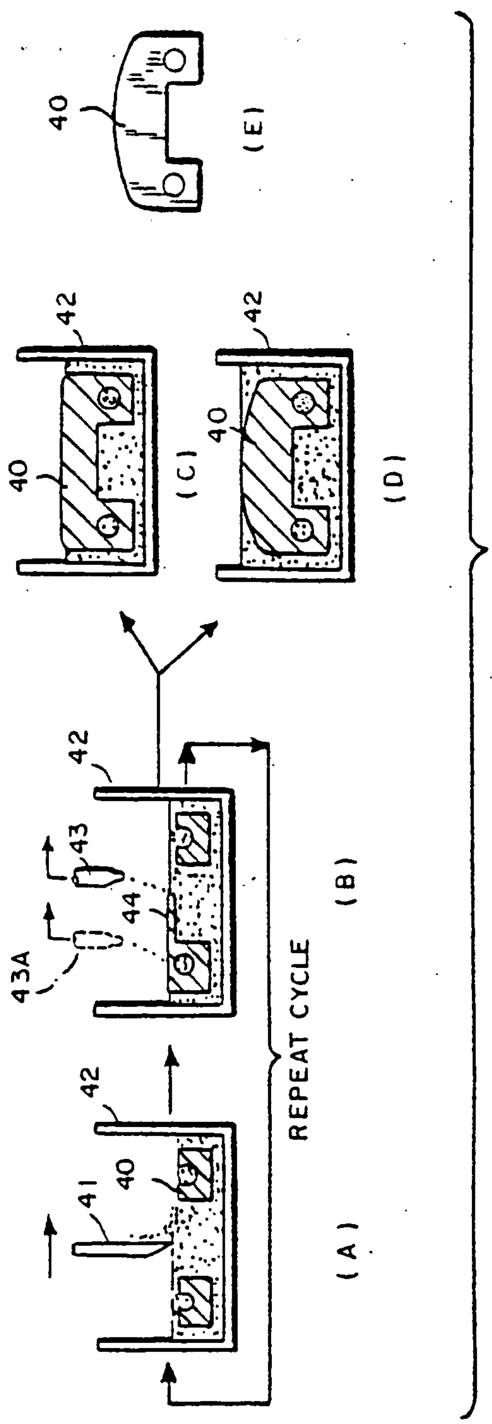


FIG.2

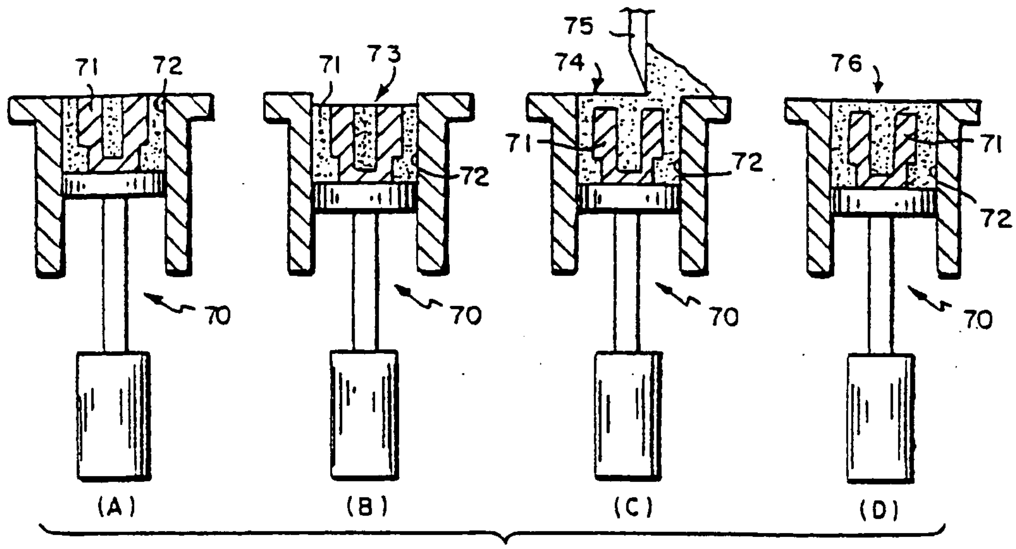


FIG.6

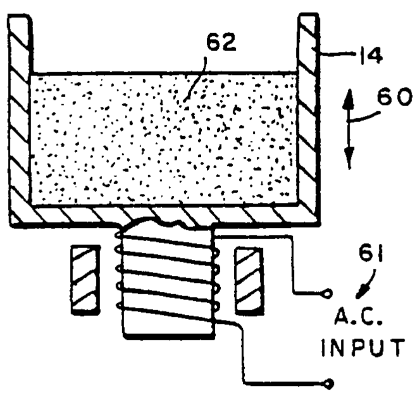


FIG.3

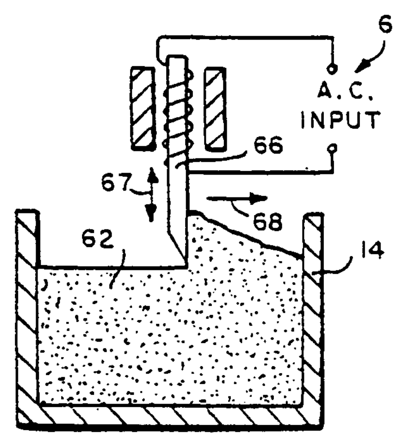


FIG.5

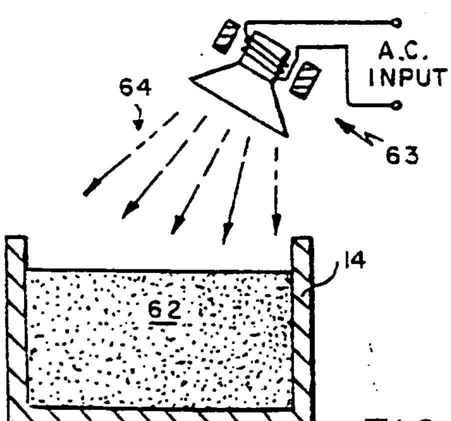
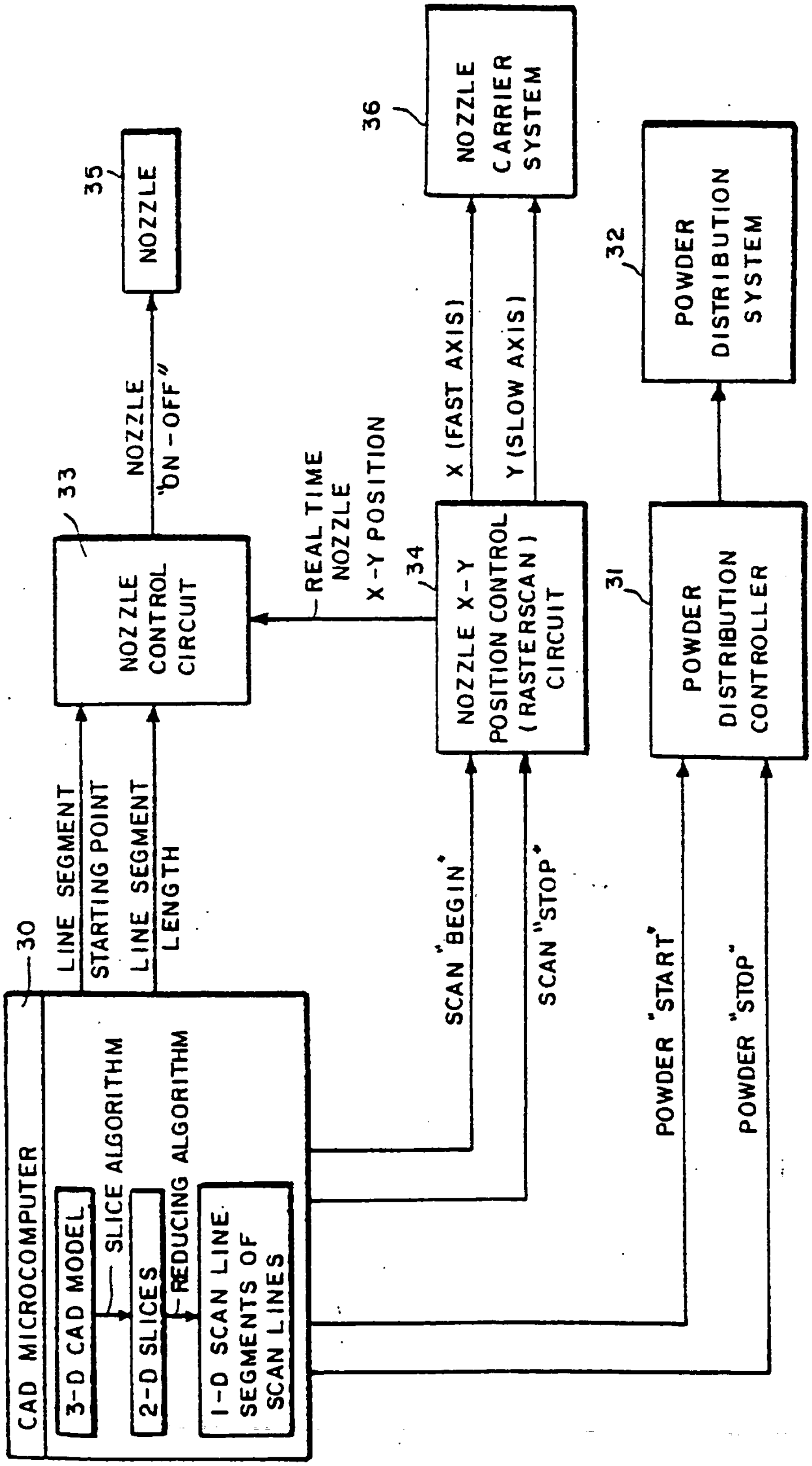


FIG. 4



CAD MICROCOMPUTER
30
3-D CAD MODEL
SLICE ALGORITHM
2-D SLICES
REDUCING ALGORITHM
I-D SCAN LINE SEGMENTS OF SCAN LINES
LINE SEGMENT STARTING POINT
LINE SEGMENT LENGTH
SCAN "BEGIN"
SCAN "STOP"
POWDER "START"
POWDER "STOP"
33
NOZZLE CONTROL CIRCUIT
NOZZLE "ON-OFF"
35
NOZZLE
REAL TIME NOZZLE X-Y POSITION
34
NOZZLE X-Y POSITION CONTROL (RASTERSCAN) CIRCUIT
X (FAST AXIS)
Y (SLOW AXIS)
36
NOZZLE CARRIER SYSTEM
31
POWDER DISTRIBUTION CONTROLLER
32
POWDER DISTRIBUTION SYSTEM

FIG. 9

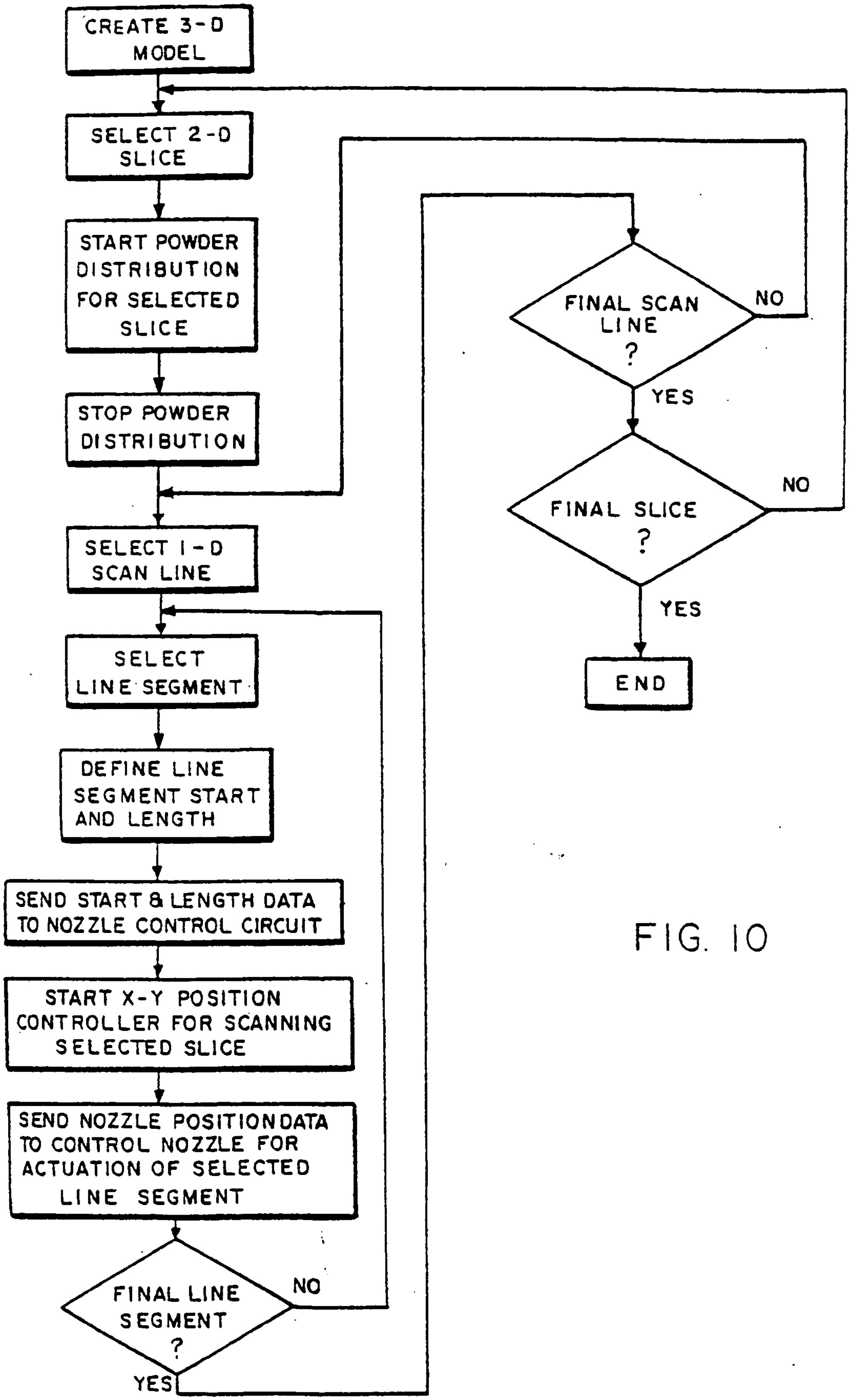

CREATE 3-D MODEL
SELECT 2-D SLICE
START POWDER DISTRIBUTION FOR SELECTED SLICE
STOP POWDER DISTRIBUTION
SELECT 1-D SCAN LINE
SELECT LINE SEGMENT
DEFINE LINE SEGMENT START AND LENGTH
SEND START & LENGTH DATA TO NOZZLE CONTROL CIRCUIT
START X-Y POSITION CONTROLLER FOR SCANNING SELECTED SLICE
SEND NOZZLE POSITION DATA TO CONTROL NOZZLE FOR ACTUATION OF SELECTED LINE SEGMENT
FINAL LINE SEGMENT ?
NO
YES
FINAL SCAN LINE ?
NO
YES
FINAL SLICE ?
NO
YES
END

FIG. 10

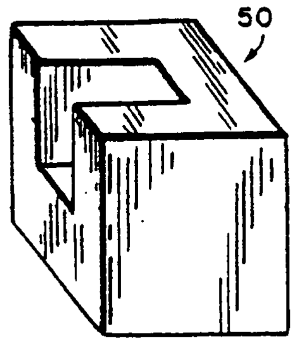


FIG. 11

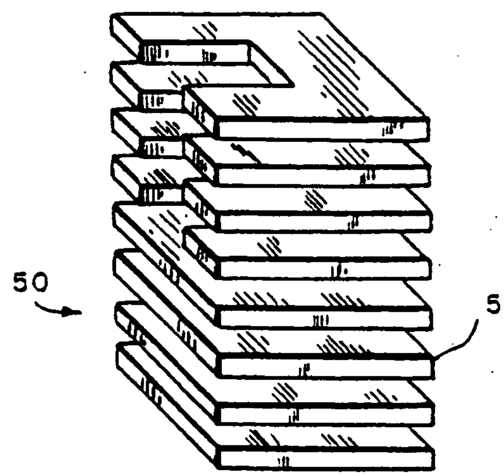


FIG. 12

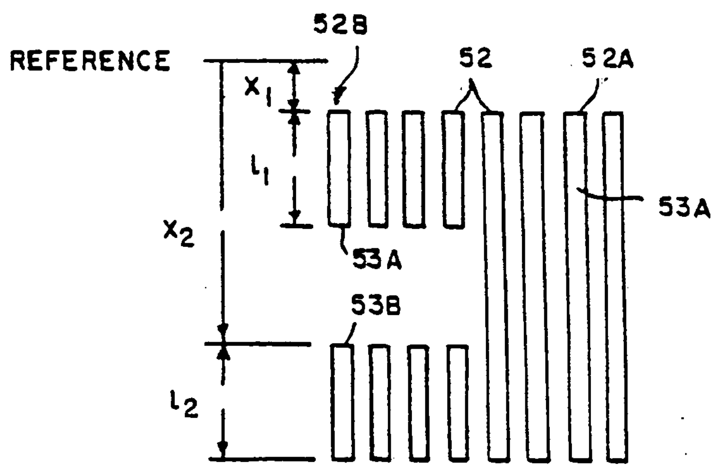


FIG. 13